Hydraulic Conductivity, Aggregate Stability and Suitability Assessment of Soil Groups for Rice Production in South Eastern Nigeria.

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Abstract

This study investigated saturated hydraulic conductivity (Ksat) and aggregate stability as well as suitability of South East soils for rice production. Core and composite auger soil samples were collected at 0 – 15 cm and 15 – 30 cm from each soils groups of the respective locations for standard routine soil analysis. Also, at each location, a profile pits was sunk for non-parametric soil suitability assessment. The soil samples were analysed for the following parameters: Particle size distribution was determined by the Pipette method. Bulk density, total porosity and moisture content were determined using core sample method, numerical method and gravimetric method.
Analysis of variance (ANOVA) was used to estimate the degree of variability existing among soil properties in the study site. Pearson correlation analysis was implemented to determine the relationship between the soil properties. Multivariate statistical analysis such as the principal component analysis (PCA) was also carried out to determine relationship among soil variables.

Assessed soil properties *showed* differences ($p < 0.05$) among micro aggregate stability indices Dispersion Ratio (DR), Clay Dispersion Index (CDI), and Clay Flocculation Index (CFI) and particle size distribution, porosity, moisture contents, as well as organic carbon/matter, nitrogen and phosphorus but no differences ($p < 0.05$) in Saturated Hydraulic Conductivity (Ksat), and macro aggregate stability indices (WSA > 2 mm, Mean Weight Diameter (MWD and Gram Mean Weight Diameter (GMWD) as well as Aggregated Silt and Clay (ASC) of the respective studied soils of alluvium deposits, coastal plain sands, coal measures, false-bedded sandstones and shale soil groups. The soils indicated low CFI compared to CDI, hence indicating higher content of unstable aggregates. This was seen in the correlating result where Ksat, ASC, DR and CDI increased but CFI decreased with increase in clay and silt contents, particle density, porosity, Electrical Conductivy (EC) as well as Soil organic Carbon (SOC) and decrease in sand, bulk density and P of the soils. A moderate ($pH > 5 \leq 6$) to strong ($pH < 5$) acidity, moderate ($K^+ \geq 0.4 < 0.6$ Cmol/kg) to high ($K^+ \geq 0.6 < 2.0$ Cmol/kg) K^+, low (%Al < 20 %) to moderate (%Al > 20 % < 50 %) Al^{3+}, moderate ($Mg^{2+} \geq 0.5 < 2.5$ Cmol/kg) Mg^{2+} and high (%BS > 50 %) base saturation as well as a generally favorable bulk density (< 1.60 g/cm^3), EC (< 2500 µS/cm) and Na^{2+} concentration (Exchange Sodium Percentage (ESP) < 10 %) for plants production observed across the studied soils. PCA results indicated high dependence of southeast Nigeria soils to texture, bulk density, porosity, Ksat, EC, OC, N, P, K^+, Ca^{2+}, Na^+, Al^{3+} and H^+ as well as ASC, DR, CDI and CFI. However, suitability of the soils for rice production was generally observed to be limited by the fertility status of the soils, irrespective of the conducive climatic and soil physical characteristics of the area. Therefore implying that soils of South Eastern Nigeria are characterized by high susceptibility to physical degradation and low inherent fertility, and thus requires conservative agricultural practices, especially incorporation of organic residues, mulching and minimum tillage practices.

Keywords: Hydraulic Conductivity, Aggregate Stability, Rice Production, Soil Crops, Suitability Assessment

Introduction

The need for proper and effective management of soil resources for sustainable yet profitable crop production as well as address problems of food insecurity especially in the South eastern region of Nigeria, remains a huge task in Nigeria (Ogueri and Nze, 2017). According to Ufot *et al.* (2016), south east Nigeria is a tropical rainforest, but lately derived savannah agro-ecological one, characterized by soils prone to degradation especially physical degradation such as erosion (Enyioko *et al.* 2019). This conformed Igwe, (2012) report that the region exhibits a gradual but constant landscape dissection due to soil erosion by water. Unfortunately ,in an attempt to enhance optimal crop productivity to curb food insecurity in the region, attributed to constant population explosion and stiff competition for land space for other land uses (Hati *et al.,* 2005), farmers practice continuous and intensive cultivation (Anikwe, 2008), hence resulting in misuse and improper soil resource management, consequently exposing the degradable prone soils of the region to degradation.

Proper management and optimal use of soil resources in the region will therefore require thorough evaluation of soil as well as its behaviours under defined influences. Sumithra *et al*. (2013) stated that soil types vary widely throughout the world, depending on location (geology, climate and vegetation) of soil with its corresponding variation in the combination of physical, chemical and biological properties and will therefore differ in their productivity, hence will need differential management practices. Consequently, to optimize use of soil resources with infinitesimal risk of degradation and enable accurate prediction of possible soil potentials (suitability or capability) to produce specific crops optimally in water erosion prone south east Nigeria, a thorough evaluation of soil characteristics, especially oil-water characteristic sand stability status is needed. It is for this apparent need of effective soil resource management for enhanced and sustainable crop productivity in south eastern Nigeria, that necessitated the assessment of hydraulic conductivity and aggregate stability of soil derived from alluvium, coastal plain sand, coal measures, sandstones and shale parent materials predominant in south eastern Nigeria (FMARD. 2001), and investigate their possible suitability to produce rice, an important staple food and most productive cereal crop consumed in the world. The outcome from this experiment will assist farmers and other critical land users in proper planning and use as well as modification of potential soils for optimal production of rice in southeast area of Nigeria. The objective of the study was to investigate the hydraulic conductivity, aggregate stability and suitability of growing rice on soils of south eastern Nigeria.

Materials and Methods

Research Area

Theresearch was carried out in Abia, Ebonyi, Enugu and Imo states of southeast agro-ecological zone of Nigeria, located on latitudes 5^0 06'N to 6^0 34'N of the Equator and longitudes 6^0 38'E and 8^0 08'E of the Greenwich (Prime) Meridian (Microsoft Corporation, 2009) with land mass of about 41,440 km^2 and elevation of 52m above sea level. The area lies within the humid tropical ecosystem with high relative humidity, atmospheric temperature and bimodal rainfall pattern. The mean annual atmospheric temperature ranges from 28 ± 8^0C, mean annual rainfall range from 2750± 250mm and annual relative humidity of 80 ± 10 % (NIMET, 2017). According to FMARD (2001), soils of south eastern Nigeria are derived majorly from alluvium deposits, coastal plain sands, lower and upper coal measures, as well as shale and sandstones parent materials and are predominantly ultisols, with entisols and inceptisols dominating the coastal end. The area has a rainforest vegetation whose density has been drastically altered and modified into a derived savannah by human activities such as bush burning, agriculture and construction works, contributing to the gully erosion problem that is prominent in the area (Uwakwe, 2012).

Research Operations

A reconnaissance field survey was carried out in order to have a general view and familiarize with the study area with the aid of a soil map. Five locations each in Abia, Ebonyi, Enugu and Imo states were selected in line with the prevailing soils groups (soils derived from alluvium deposits, coastal plain sands and coal measures, as well as shale and sandstones parent materials)in the area. Consequently, the delineated locations were Akwette (Abia), Ikwo (Ebonyi), Adanni (Enugu) and Umuehi (Imo) for Alluvium deposits; Asaga (Abia), Afikpo (Ebonyi), Nsukka (Enugu) and Umu-Ezageh (Imo) for Coal Measures; Obehie (Abia), Owutu-Edda (Ebonyi), Uzo-Uwani (Enugu) and Nekede (Imo) for Coastal plains; Isuochi (Abia), Igbere

(Ebonyi), Ngwo (Enugu) and Ihube (Imo) for Sandstones; Ajata-Ibeku (Abia), Amuvi (Ebonyi), Agwu (Enugu) and Isu (Imo).

However, to address the objectives of the study, core and composite auger soil samples were collected at 0 – 15 cm and 15 – 30 cm from each soils groups of the respective locations for standard routine soil analysis. Also, at each location, a profile pits was sunk for non-parametric soil suitability assessment following the guideline of FAO (2006).

Soil Analysis

The soil samples were analysed for the following parameters:

Particle size distribution was determined by the Pipette method as described by SSS (2006). Bulk and particle densities, total porosity and moisture content were determined using core sample method described by Grossman and Reinsch (2002), numerical method as outlined by Redding and Devito (2006) and gravimetric method described by Grossman and Reinsch (2002) respectively and were calculated as follows:

$$\text{Soil bulk density (g/cm}^3\text{)} = (W_3 - W_1) \div V$$

$$\text{Soil particle density (g/cm}^3\text{)} = W_S \div V_S$$

$$\text{Soil Porosity (\%)} = [1 - (BD \div PD)] \times 100$$

$$\text{Soil moisture content (g/g)} = [(W_2 - W_1) - (W_3 - W_1)] \div (W_3 - W_1)$$

Where $(W_2 - W_1)$ = Wet weight of soil;$(W_3 - W_1)$ = Oven dried weight of soil;V = Volume of core sampler = volume of soil; W_S = Compressed weight of soil with pore spaces; V_S = Volume of compressed soil with pore spaces; BD = Bulk Density and PD = Particle Density.

Saturated hydraulic conductivity (Ksat) was determined by the constant head method as outlined by Reynolds *et al*, (2002) and calculated using the Darcy's equation:

$$K_{sat} = \theta / At \times L / \Delta H$$

Where θ = volume of water per unit time; A = area of core sampler; t = unit time in minutes / hours; L = length of core; and ΔH = hydraulic head difference

Mean weight diameter was determined using method given below as described by NCRS (1996).

$$MWD = \sum_{i=1}^{n} x_i w_i$$

$$GMD = \exp\left[\left(\sum_{i=1}^{n} w_i \lg x_i\right) \Big/ \left(\sum_{i=1}^{n} w_i\right)\right]$$

Where X_i = arithmetic mean diameter of the I = 1and 1 sieve openings (mm); W_i = proportion of the total sample weight (uncorrected for sands and gravel) occurring in the fraction (dimensionless), and n= total number of size fractions.

Micro aggregate stability indices were calculated using the relationship stated below according to Igwe *et al.* (1999):

Clay Dispersion Index, CDI = [% clay (water) / % clay (calgon)] x 100

Dispersion Ratio, DR = [% silt + % clay (water)] / [% silt + % clay (calgon)]

Aggregated Silt and Clay, ASC = [% silt + % clay (calgon)] – [% silt + % clay (water)]

Clay Flocculation Index, CFI = [1 – {% clay (water) / % clay (calgon)}] x 100

Higher values of ASC and CFI indices imply greater soil stability, but higher values of DR and CDI indicates lower stability.

Macro aggregate stability was accessed using the water stable aggregates (WSA) of the 2 mm air-dried samples, determined using a nest of sieves 2, 1, 0.5, and 0.25 mm in diameter as described by NCRS (1996). WSA > 0.25 mm were used to assess aggregate stability, whereas WSA< 0.25 mm measured the unstable aggregates.

Soil pH was measured in 1:2.5 soil – water suspension methods using a standard pH meter as described by Havlin *et al.* (2000). Soil organic matter content was calculated by multiplying Van Bemmelen's correction factor of 1.724 by organic carbon determined by modified Walkley-Black dichromate digestion method as described by Laurenz and Lal, (2016). Total nitrogen was determined by the Kjeldahl digestion and distillation method as described by Rathore *et al*, (2008). Phosphorus was determined using a spectrophotometer by the blue ammonium molybdate method as described by Havlin *et al.* (2000). Exchangeable acidity (H^+ and Al^{3+}) was extracted using 1 N potassium chloride solution and titrated with 0.05 N sodium hydroxide solution as described by Udo *et al*. (2009). Exchangeable bases (K^+, Na^+, Ca^{2+} and Mg^{2+}) were extracted with 1 N ammonium acetate solution, while K^+ and Na^+ were read using the Gallenkamp flame photometer, Ca^{2+} and Mg^{2+} were determined by ethylene diaminetetracetic acid (EDTA) complexiometric titration method as described by Udo *et al*. (2009). Effective cation exchange capacity, percent base and percent aluminium saturations were estimated using standard procedures outlined by Soil Survey Staff, 2010).

Land Suitability Evaluation

The soils were evaluated for its suitability for rice production using the conventional non-parametric method (Udo *et al*., 2011), where soils were placed in suitability classes by matching their characteristics with the established requirements for rice production respectively.

Statistical Analysis

Data collected from the study site was subjected to descriptive statistics. Also, analysis of variance (ANOVA) was used to estimate the degree of variability existing among soil properties in the study site. Pearson correlation analysis was implemented to determine the relationship between the soil properties. Multivariate statistical analysis such as the principal component analysis (PCA) was also carried out to determine relationship among soil variables.

Results and Discussion

Physical Properties of Soils of Existing Soil Groups of South East Nigeria

Mechanical Characteristics of Studied Soils

Results on Table 1 and figure 1 respectively reveals the particle size distribution, bulk density (BD) and particle density (PD) of the existing soil groups of south eastern Nigeria.

sand fractions dominated the other fractions in the particle size distribution with recorded means of 80.79 % > 76.48 % > 66.12 % > 57.93 % > 43.02 % for soils of alluvium, coastal plains, coal measures, sandstones and shale soil groups respectively, with significant parent material effects ($p < 0.05$) on the mean sand contents among the studied soil groups. This therefore confirms Enyioko *et al*. (2019) reports that the sandy nature of soils was the reflection of the parent materials from which the soils were formed. Clay was generally low, which could be attributed to leaching and the pedogenic process of translocation of clay materials down a soil profile, due to high rainfall status of the South Eastern region of Nigeria(Obi and Akinbola, 2009). Clay fractions recorded mean values of 14.65 % < 16.83 % < 21.94 %<31.98 % < 34.67 % for derived soils of alluvium, coastal plains, coal measures, sandstones and shale respectively. Also, significant parent material effects ($p < 0.05$) were observed among clay fractions of the respective soil groups. Silt also recorded generally low values noted by Nkwopara *et al*. (2017)to be effects of silt dependence on high weatherability rate of soil. Silt fractions recorded means of 4.56 % < 6.52 %<10.10 %<11.94 %< 22.32 % for soils of alluvium, coastal plains, sandstones, coal measures and shale soil groups, which differed ($p < 0.05$) significantly among the soil groups.

BD of ≤ 1.34 g/cm³ and particle density range of 2.60 – 2.78 g/cm³ were recorded among soils of the different soil groups. Recorded BD values were below the critical limit of 1.60 g/cm³ recommended for optimal air and water movement in soil (Esu, 2005) as well as recommended limit of 1.75 – 1.85 g/cm³ for root penetration(SSS, 2010). BD showed trend of 1.32 g/cm³ > 1.29g/cm³ > 1.22g/cm³ > 1.10 g/cm³ > 1.07 g/cm³ for soils of alluvium, coastal plains, coal measures, sandstones and shale respectively. However, BD recorded in soils of alluvium and coastal plain sands were significantly higher than those for sandstones and shale derived soils respectively. PD was observed to vary inversely with BD with trend of 2.61 g/cm³ < 2.63 g/cm³ < 2.66 g/cm³ < 2.72 g/cm³ < 2.73 g/cm³ for soils of alluvium, coastal plains, coal measures, sandstones and shale respectively, but differed ($p < 0.05$) only between mean values of alluvium and shale soils.

Table 1: Particle Size Distribution, Bulk Density and Particle Density of Studied Soils

Location	Sand	Clay	Silt	Texture	BD	PD
	←	(%)	→		←	(g/cm³) →
			Alluvium/Deltaic Plains			
Akwete	81.90	13.33	4.77	LS	1.34	2.60
Ikwo	82.98	14.10	2.92	LS	1.33	2.61
Adani	78.30	14.85	6.85	LS	1.32	2.61
Umuehi	79.99	16.31	3.70	SL	1.30	2.62

International Journal of Scientific Engineering and Applied Science (IJSEAS) – Volume-7, Issue-6, June 2021
ISSN: 2395-3470
www.ijseas.com

Mean	**80.79**	**14.65**	**4.56**		**1.32**	**2.61**
Coal Measures						
Asaga	78.54	13.20	8.26	LS	1.34	2.60
Afikpo	47.43	34.06	18.51	SCL	1.07	2.73
Nsukka	67.97	21.35	10.68	SCL	1.22	2.66
UmuEzageh	70.55	19.15	10.30	SL	1.25	2.64
Mean	**66.12**	**21.94**	**11.94**		**1.22**	**2.66**
Coastal Plain Sands						
Obehie	74.87	18.33	6.08	SL	1.26	2.64
Owutu Edda	75.97	14.83	9.20	LS	1.32	2.61
Uzo Uwani	76.58	21.34	2.08	SCL	1.22	2.66
Nekede	78.50	12.80	8.70	LS	1.35	2.60
Mean	**76.48**	**16.83**	**6.52**		**1.29**	**2.63**
False-bedded Sandstones						
Isuochi	50.80	37.80	11.40	SC	1.03	2.75
Igbere	63.90	29.70	6.40	SCL	1.12	2.71
Ngwo	49.30	38.60	12.10	SC	1.02	2.75
Ihube	67.70	21.80	10.50	SCL	1.22	2.66
Mean	**57.93**	**31.98**	**10.10**		**1.10**	**2.72**
Shale						
Ajata-Ibeku	41.09	30.10	28.81	CL	1.11	2.71
Amuvi	48.47	37.36	14.17	SC	1.04	2.75
Agwu	24.00	46.00	30.00	C	0.96	2.78
Isu	58.50	25.20	16.30	SCL	1.17	2.68
Mean	**43.02**	**34.67**	**22.32**		**1.07**	**2.73**
Lsd (0.05)	**1.86**	**1.47**	**1.27**		**0.16**	**0.11**

BD = Bulk Density, PD = Particle Density, LS = Loamy Sand, SL = Sandy Loam, SCL = Sandy Clay Loam, SC = Sandy Clay, CL = Clay Loam and C = Clay

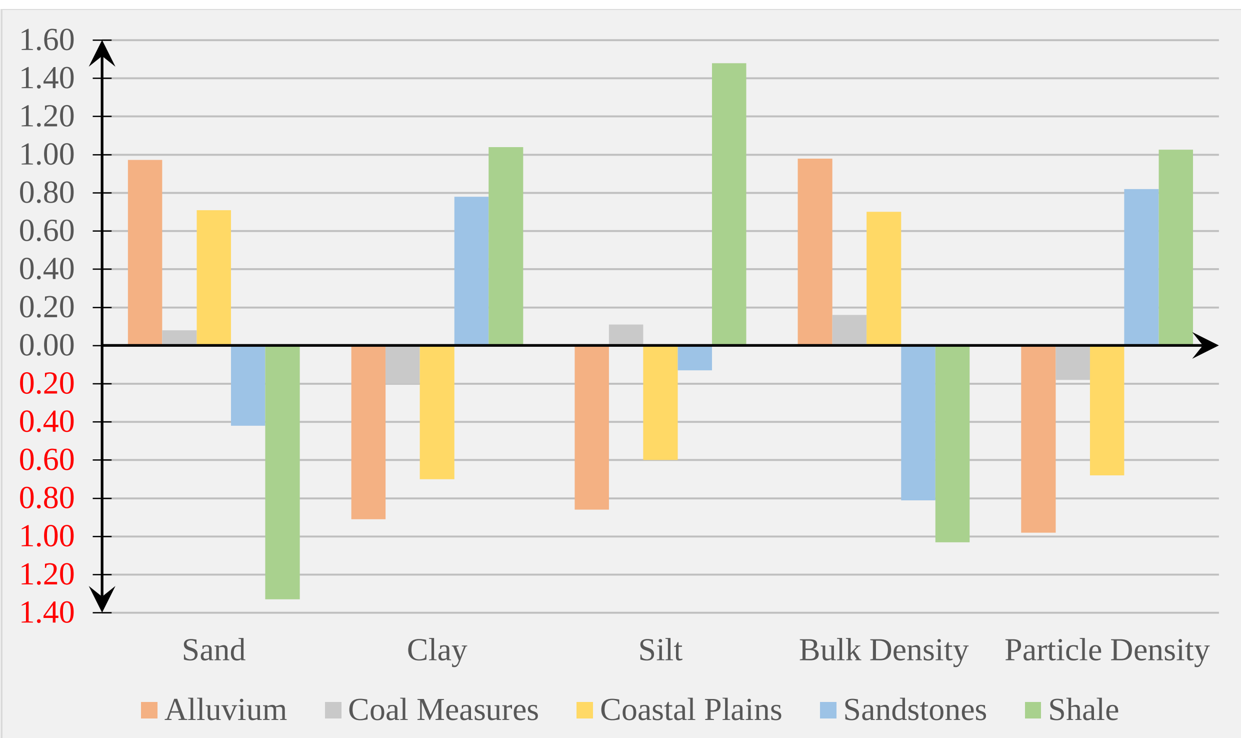

Figure 1: Chart Showing Particle Size Distribution, Bulk Density and Particle Density of Studied Soil

Hydro-physical Characteristics of Studied Soils

Results on Table 2 and figure 2 respectively reveals the porosity (%P), moisture content (Mc) and saturated hydraulic conductivity (Ksat) of the existing soil groups of south eastern Nigeria.

%P values of 48.37 – 65.35 % observed to be relatively high showed means values of 60.76 % >59.61 % >53.98 % > 50.98 %> 49.46 % for derived soils of shale, sandstones, coal measures, coastal plains and alluvium soil groups respectively, with significant differences ($p < 0.05$) among the respective mean %P of the studied soil groups. The relative high porosity is the direct result of low bulk density, hence, agreeing with the inverse relationship between %P and BD according to Ewulo et al. (2008).

MC of 12.93 – 15.19 % with means of 14.63 % > 14.59 % > 14.31 % > 14 % > 13.72 % for soils of alluvium, sandstones, coastal plains, coal measures and shale were observed. Significant differences ($p < 0.05$) were recorded moisture contents among soils formed from shale and coastal plain sands as well as among soils from both shale and coal measure respectively and those of sandstones and alluvium deposits.

Ksat recorded showed irregular trend ranging from 0.04 – 0.11 cm/min with no significant ($p < 0.05$) difference among soils of the studied soil groups.

Table 2: Porosity, Moisture Content and Saturated Hydraulic Conductivity of Studied Soils

Location	%P	MC (%)	Ksat (cm/min)
	Alluvium/Deltaic Plains		
Akwete	48.47	14.51	0.04
Ikwo	49.05	14.91	0.05
Adani	49.61	14.24	0.05
Umuehi	50.66	14.85	0.05
Mean	**49.45**	**14.63**	**0.05**
	Coal Measures		
Asaga	48.37	13.80	0.04
Afikpo	60.90	14.02	0.10
Nsukka	54.04	14.13	0.06
UmuEzageh	52.62	14.04	0.06
Mean	**53.98**	**14.00**	**0.06**
	Coastal Plain Sands		
Obehie	52.07	14.58	0.05
Owutu Edda	49.59	13.82	0.05

Uzo Uwani	54.04	15.19	0.06
Nekede	48.06	13.66	0.04
Mean	**50.94**	**14.31**	**0.05**
		False-bedded Sandstones	
Isuochi	62.49	14.66	0.11
Igbere	58.80	14.88	0.09
Ngwo	62.80	14.63	0.11
Ihube	54.33	14.18	0.06
Mean	**59.61**	**14.59**	**0.09**
		Shale	
Ajata-Ibeku	59.01	12.93	0.09
Amuvi	62.31	14.45	0.11
Agwu	65.35	13.73	0.13
Isu	56.37	13.75	0.07
Mean	**60.76**	**13.72**	**0.10**
Lsd (0.05)	**1.09**	**0.34**	**0.08**

%P = Porosity, MC = Moisture Content, Ksat = Saturated Hydraulic Conductivity

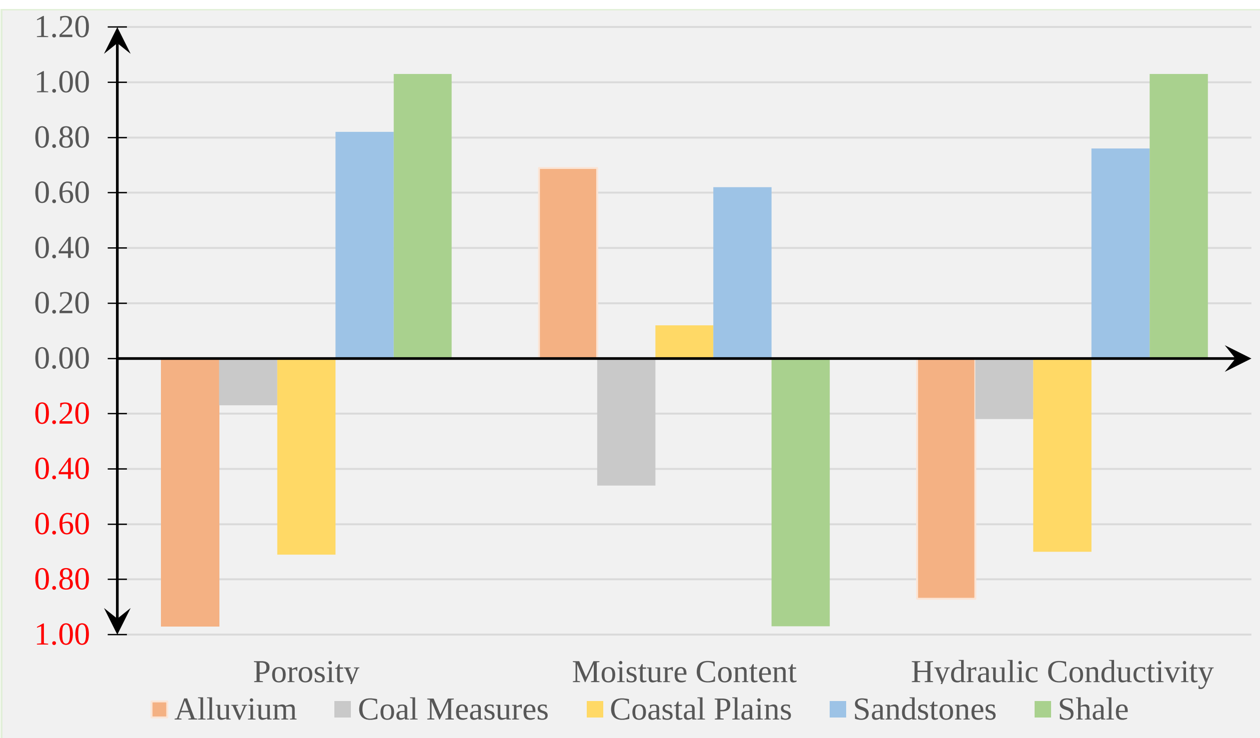

Figure 2: Chart Showing Porosity, Moisture Content and Saturated Hydraulic Conductivity of Studied Soils

Chemical Properties of Soils of Existing Soil Groups of South East Nigeria

Soil Chemical Reactions

Results on Table 3 and figure 3 respectively reveals the electrical conductivity (EC), pH, soil organic carbon (SOC) and soil organic matter (SOM) contents, including total nitrogen (N) and available phosphorus (P) of the existing soil groups of south eastern Nigeria.

EC of the studied soils ranged between 9.32 – 68.84 µS/cm with means of 9.95 µS/cm <10.10 µS/cm < 10.27µS/cm < 11.92µS/cm < 50.53 µS/cm, from alluvium, sandstones, coastal plains, coal measures and shale soil groups respectively. This indicates that EC of the studied soils were below the permissible level of 2500 µS/cm (1600 ppm salt) for crop production (Horneck *et al.*, 2011). However, shale derived soils recorded higher ($p < 0.05$) EC compared to soils of other soil groups. Also, differences ($p < 0.05$) in EC were observed among coal measure soils and alluvium soils. .

Soil pH of the studied soils ranged from4.47(strongly acidic) – 5.52 (moderately acidic), indicating that the soils of south eastern Nigeria are generally acidic soils. Acidic nature of the soils may be attributed to the presence of high exchange acidity and high rainfall pattern of the study area which tend to render the soils prone to erosion and high base leaching as reported by Udo *et al.* (2009). Results indicated that the strongly acidic soils of coastal plain sands and sandstones with respective means of 4.54and 4.86 differed ($p < 0.05$) with moderately acidic soils of shale, coal measure and alluvium with pH of 5.23, 5.31 and 5.51 respectively. However, pH of coastal plain sandsoils also differed ($p < 0.05$) with pH of sandstone soils.

SOC observed was generally moderate (Horneck *et al.*, 2011) and ranged from 0.61 – 1.72 % with trend of 0.66 % in alluvium< 0.68 % recorded in coastal plain sands< 0.69 % observed in soils of sandstones < 0.75 % in coal measure soils < 1.50 % in shale soils. Results also indicated existing variability ($p < 0.05$) between SOC of shale soils and soils of other parent materials. SOM ranged between 1.06 – 2.96 %, with trend and variability ($p < 0.05$) among respective soil groups similar to SOC. This similarity is because SOM content is a surrogate for SOC, which constitute 58 % of its composition, hence SOM was also moderate.

N of the studied soil groups ranged from 0.73 – 1.31 g/kg, with respective mean values of 0.17 g/kg for shale soils, < 0.97 g/kg for coal measure soils, < 1.06 g/kg for coastal plain sand soils, < 1.12 g/kg for sandstone soils, < 1.14 g/kg for alluvium soils. This implies that soils of coal measure and shale had low (< 1g/kg) N content, while alluvium, coastal plains and sandstones had moderate (1 – 1.5 g/kg) amount of N (Horneck *et al.*, 2011). However, significantly lower ($p < 0.05$) N content was observed in shale derived soils compared to soils of other soil groups.

Available P indicated range of 4.78 – 10.74 mg/kg, observed to be low (< 20 mg/kg) (Horneck *et al.*, 2011), with trend of 5.64 mg/kg <9.73 mg/kg < 10.19 mg/kg < 10.25 mg/kg < 10.40 mg/kg for soils of shale, coal measure, sandstone, coastal plain sand and alluvium deposit respectively. Result showed differences ($p < 0.05$) among P contents of shale and coal measure soils and also indicated that both shale and coastal plain sand soils differed ($p < 0.05$) in available P compared to those of other respective soil groups.

Table 3: Chemical Reactions in the Studied Soils

Location	Ec (µS/cm)	pH	SOC (%)	SOM (%)	N (g/kg)	Av. P (mg/kg)
			Alluvium/Deltaic Plains			
Akwete	9.98	5.51	0.66	1.14	1.10	10.38
Ikwo	9.95	5.52	0.66	1.14	1.22	10.39
Adani	10.36	5.50	0.68	1.18	1.03	10.21
Umuehi	9.49	5.51	0.63	1.08	1.20	10.63
Mean	**9.95**	**5.51**	**0.66**	**1.14**	**1.14**	**10.40**
			Coal Measures			
Asaga	10.21	5.26	0.68	1.16	0.92	10.27
Afikpo	15.19	5.35	0.88	1.51	0.97	8.85
Nsukka	11.34	5.15	0.73	1.27	1.00	9.83
UmuEzageh	10.92	5.46	0.71	1.23	0.97	9.98
Mean	**11.92**	**5.31**	**0.75**	**1.29**	**0.97**	**9.73**
			Coastal Plain Sands			
Obehie	10.50	4.55	0.69	1.19	1.12	10.15
Owutu Edda	10.15	4.53	0.67	1.16	0.92	10.30
Uzo Uwani	10.60	4.59	0.70	1.20	1.31	10.11
Nekede	9.84	4.47	0.65	1.12	0.88	10.45
Mean	**10.27**	**4.54**	**0.68**	**1.17**	**1.06**	**10.25**
			False-bedded Sandstones			
Isuochi	11.31	4.79	0.73	1.26	1.14	9.84
Igbere	9.91	4.87	0.66	1.13	1.21	10.41
Ngwo	11.49	4.79	0.74	1.28	1.13	9.78
Ihube	9.32	4.99	0.61	1.06	1.01	10.74
Mean	**10.51**	**4.86**	**0.69**	**1.18**	**1.12**	**10.19**
			Shale			
Ajata-Ibeku	48.28	5.16	1.48	2.55	0.73	5.69
Amuvi	48.21	5.28	1.48	2.55	1.08	5.69
Agwu	68.84	5.08	1.72	2.96	0.90	4.78
Isu	36.78	5.40	1.32	2.28	0.90	6.40
Mean	**50.53**	**5.23**	**1.50**	**2.59**	**0.90**	**5.64**
Lsd (0.05)	**1.91**	**0.28**	**0.27**	**0.35**	**0.17**	**0.64**

EC = Electrical Conductivity, SOC = Soil Organic Carbon, SOM = Soil Organic Matter, N = Nitrogen and Av. P = Available Phosphorus.

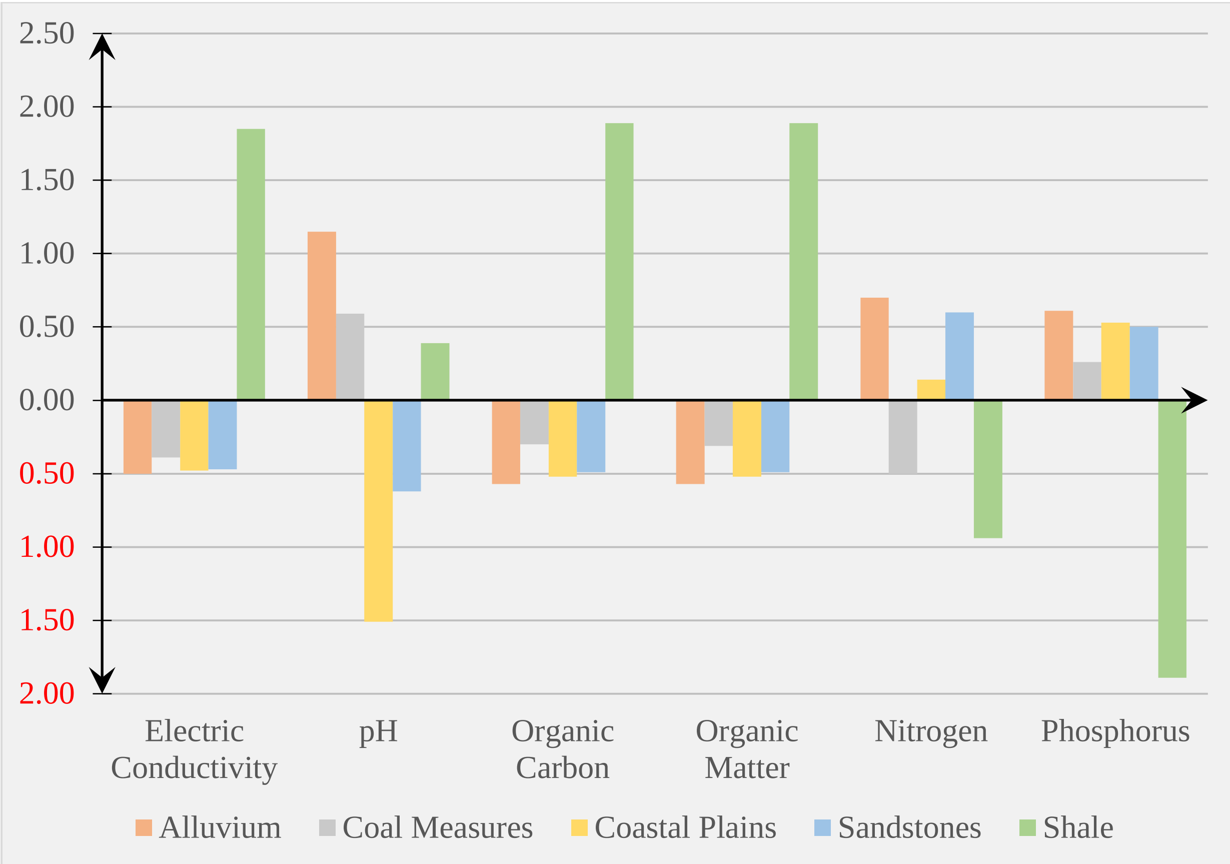

Figure 3: Chart Showing Chemical Reactions in the Studied Soils

Cations

Results on Table 4 and figure 4 respectively reveals the exchangeable potassium (K^+), calcium (Ca^{2+}), magnesium (Mg^{2+}), sodium (Na^+), aluminium (Al^{3+}) and Hydrogen (H^+) ions as well as effective cation exchange capacity (ECEC), Base Saturation (%BS) and Aluminium Saturation (%Al) of the existing soil groups of south eastern Nigeria.

K^+ ranged between 0.37 – 0.73 Cmol/kg with means of 0.62 Cmol/kg > 0.60 Cmol/kg > 0.54 Cmol/kg > 0.50 Cmol/kg > 0.44 Cmol/kg for sandstones, alluvium, shale, coal measures and coastal plains soil groups respectively. This indicates that K^+ was moderate ($K^+ \geq 0.4 < 0.6$ Cmol/kg) in soils of alluvium, shale, coal measures and coastal plain sands and high ($K^+ \geq 0.6 <$ 2.0 Cmol/kg) in sandstone soils as rated by Horneck *et al.*(2011).However, differences ($p < 0.05$) were seen between K^+ in coastal plain sand soils and those in alluvium and sandstone soils respectively.Ca^{2+} was observed to show trend of 1.69 Cmol/kg in sandstone soils > 1.65 Cmol/kg in alluvium soils > 1.54 Cmol/kg in both coal measure and shale soils > 1.39 Cmol/kg in coastal plain sand soils, and recorded differences in Ca^{2+} of coastal plain sand soils and those in alluvium and sandstone soils respectively, as observed for K^+. Mg^{2+} showed trend of 0.82

Cmol/kg in sandstone soils > 0.79 Cmol/kg in alluvium soils > 0.67 Cmol/kg in coal measure > 0.65 Cmol/kg in coastal plain sand soils > 0.59 Cmol/kg in shale soils, with differences ($p < 0.05$) observed between Mg^{2+} recorded in sandstone soils and shale soils. However, Mg^{2+} of the studied soils was generally moderate ($Mg^{2+} \geq 0.5 < 2.5$ Cmol/kg) as rated by Horneck *et al.* (2011).Na^{+} showed trend of 0.15 Cmol/kg recorded in alluvium, coastal plain sand and sandstone soils respectively < 0.16 Cmol/kg in coal measure soils < 0.17 Cmol/kg in shale soils. Result indicated that observed Na^{+} recorded in soils of alluvium, coastal plains and sandstones differed ($p < 0.05$) with those recorded in shale and coal measure soils respectively. Result also show differences in Na^{+} of shale and coal measure soils. Concentration of Na^{+} (exchangeable sodium percentage, ESP), given as percentage of ECEC occupied by Na^{+}, revealed that the concentration of Na^{+} in the studied soils was below the permissible level of Na^{+} content in soil (ESP < 10 %), indicating that soils of south eastern Nigeria are risk-free from degradation of soil structure and permeability associated with excessive levels of sodium in soil.Al^{3+} was observed to range from 0.54 – 1.44 Cmol/kg and show trend of coastal plain sand soils (0.77 Cmol/kg) < alluvium and sandstone soils (0.82 Cmol/kg)< coal measure soils (0.98 Cmol/kg) < shale soils (1.05 Cmol/kg) with differences observed between Al^{3+} contents in shale soils and those in respective soils of coastal plain sands, alluvium deposits and sandstones. However, concentration of Al^{3+} given by Al^{3+} saturation (%Al) indicated that respective soils of coastal plain sands, alluvium deposits and sandstones recorded low %Al (%Al < 20 %) while coal measure and shale soils were moderately saturated (%Al > 20 % < 50 %) with Al^{3+}. H^{+} recorded mean value of 1.27 Cmol/kg observed to differ ($p < 0.05$) with mean values of 0.51, 0.53, 0.68 and 0.69 Cmol/kg recorded in respective soils of shale, coal measures, sandstones and alluvium deposits.

%BS of the studied soils were generally high (> 50 %). Result however showed that %BS of respective soils of alluvium deposits (67.88 %) and sandstones (67.58 %) were higher and significantly ($p < 0.05$) different from %BS of respective soils of coal measures (65.33 %) and shale (64.22 %), also observed to be higher and significantly ($p < 0.05$) different from %BS of soils of coastal plain sands (56.27 %).ECEC observed for the studied soils ranged from 3.94 – 5.27 Cmol/kg with means showing trends of 4.36 Cmol/kg < 4.39 Cmol/kg < 4.66 Cmol/kg <

International Journal of Scientific Engineering and Applied Science (IJSEAS) – Volume-7, Issue-6, June 2021
ISSN: 2395-3470
www.ijseas.com

4.67 Cmol/kg < 4.78 Cmol/kg for respective soils of coal measures, shale, coastal plain sands, alluvium deposits and false-bedded sandstones. Results indicated however that variability ($p < 0.05$) in ECEC existed between coal measure soils and respective soils of coastal plain sands, alluvium deposits and false-bedded sandstones, as well as between shale soils and respective soils of alluvium deposits and false-bedded sandstones.

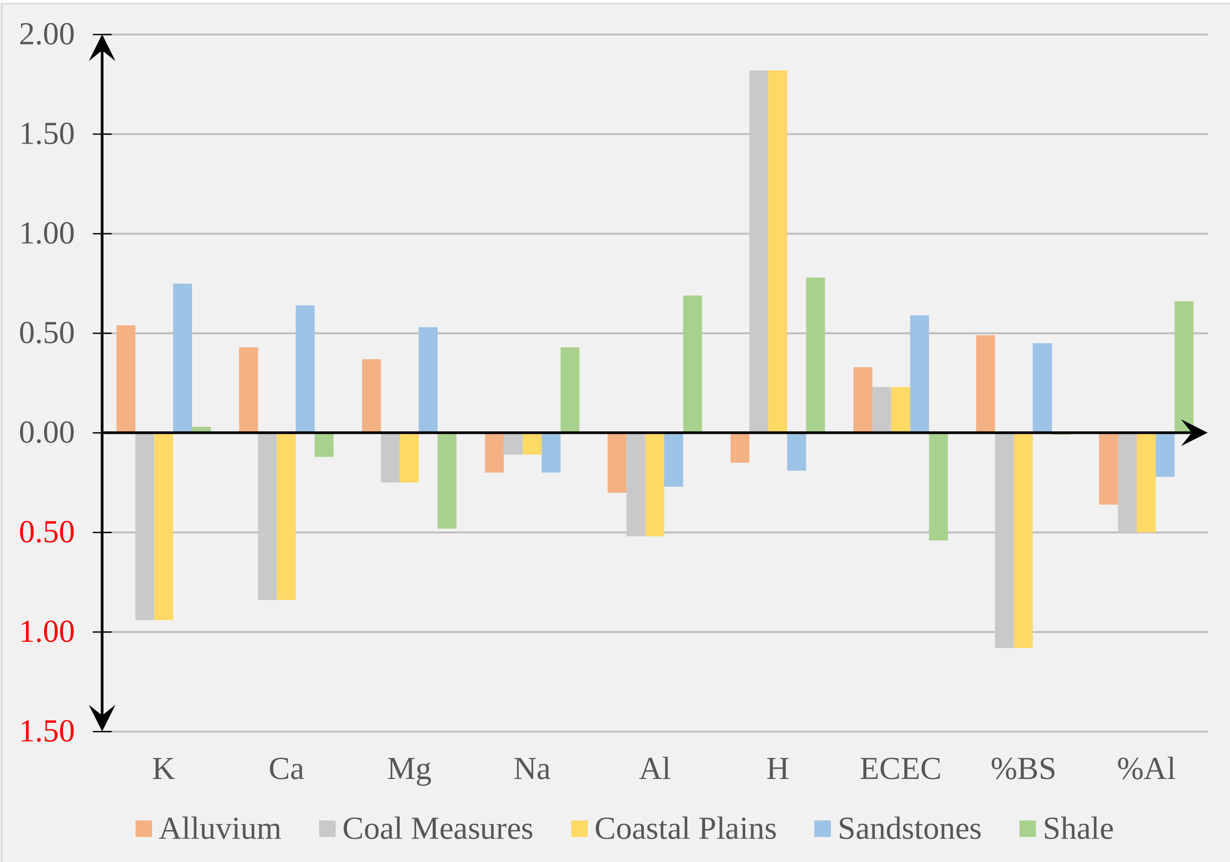

Figure 4: Chart Showing Concentration of Exchangeable Cationsin the Studied Soils

Table 4: Concentration of Exchangeable Cations in the Studied Soils

Location	K^+	Ca^{2+}	Mg^{2+}	Na^+	Al^{3+}	H^+	ECEC	%BS	%Al
	(Cmol/kg)								
Alluvium/Deltaic Plains									
Akwete	0.59	1.62	0.76	0.14	0.82	0.69	4.63	67.25	17.73
Ikwo	0.59	1.69	0.80	0.16	0.85	0.70	4.79	67.65	17.76
Adani	0.61	1.64	0.78	0.15	0.83	0.68	4.70	67.84	17.66
Umuehi	0.59	1.65	0.81	0.14	0.76	0.69	4.64	68.77	16.40
Mean	**0.60**	**1.65**	**0.79**	**0.15**	**0.82**	**0.69**	**4.69**	**67.88**	**17.39**
Coal Measures									
Asaga	0.46	1.39	0.43	0.18	1.21	0.49	4.16	59.25	29.08
Afikpo	0.58	1.62	0.75	0.13	0.90	0.53	4.51	68.35	19.86
Nsukka	0.43	1.58	0.79	0.16	0.86	0.47	4.28	69.00	19.98
UmuEzageh	0.51	1.56	0.69	0.15	0.95	0.63	4.49	64.73	21.24
Mean	**0.50**	**1.54**	**0.67**	**0.16**	**0.98**	**0.53**	**4.36**	**65.33**	**22.54**
Coastal Plain Sands									

Obehie	0.38	1.25	0.73	0.16	0.61	1.23	4.37	57.84	13.97
Owutu Edda	0.41	1.32	0.51	0.14	0.89	1.28	4.55	52.26	19.58
Uzo Uwani	0.42	1.37	0.65	0.17	0.69	1.14	4.44	58.83	15.55
Nekede	0.53	1.61	0.69	0.13	0.87	1.44	5.27	56.16	16.52
Mean	**0.44**	**1.39**	**0.65**	**0.15**	**0.77**	**1.27**	**4.66**	**56.27**	**16.41**
False-bedded Sandstones									
Isuochi	0.69	1.84	1.00	0.13	0.65	0.76	5.07	72.21	12.82
Igbere	0.73	1.93	1.11	0.10	0.54	0.65	5.07	76.44	10.70
Ngwo	0.68	1.83	0.99	0.13	0.66	0.76	5.05	71.92	13.06
Ihube	0.37	1.17	0.19	0.23	1.44	0.54	3.94	49.73	36.64
Mean	**0.62**	**1.69**	**0.82**	**0.15**	**0.82**	**0.68**	**4.78**	**67.58**	**18.31**
Shale									
Ajata-Ibeku	0.43	1.31	0.30	0.19	1.33	0.47	4.04	55.34	32.99
Amuvi	0.65	1.77	0.89	0.14	0.76	0.49	4.70	73.42	16.10
Agwu	0.54	1.53	0.59	0.15	1.06	0.49	4.34	64.44	24.32
Isu	0.54	1.53	0.59	0.18	1.05	0.57	4.46	63.66	23.56
Mean	**0.54**	**1.54**	**0.59**	**0.17**	**1.05**	**0.51**	**4.39**	**64.22**	**24.24**
Lsd (0.05)	**0.15**	**0.21**	**0.22**	**0.08**	**0.22**	**0.25**	**0.27**	**1.25**	**1.19**

K^+ = Exchangeable potassium; Ca^{2+} = Exchangeable calcium; Mg^{2+} = Exchangeable magnesium; Na^+ = Exchangeable sodium; Al^{3+} = Exchangeable Aluminium; ECEC = effective cation exchange capacity; %BS = Base saturation; %Al = Aluminium saturation

Structural Properties of Soils of Existing Soil Groups of South East Nigeria

Tables 5 and 6 as well as Figure 5 respectively reveals the macro aggregate stability characteristics (water stable aggregates, WSA; Mean weight Diameter, MWD and GMWD) and micro aggregate stability characteristics (aggregated silt and clay, ASC; dispersion ratio, DR; clay dispersion index, CDI and clay flocculation index, CFI) of the existing soil groups of south eastern Nigeria.

Result showed that WSA > 0.25 mm ranged from 1.02 – 1.62 g for all studied soils and was observed to be higher than respective WSA < 0.25 mm of 0.41 – 1.54 g, indicating that the soils had more stable aggregates than unstable aggregates. However, result showed WSA > 0.25 mm trend of coastal plain sand soils of 1.41 g>sandstone soils of 1.38 > coal measure and shale soils of 1.34 g respectively > alluvium deposited soils of 1.28 g but there were no significant ($p < 0.05$) difference observed among them.MWD ranged from 1.51 – 1.91 g with mean values showing trend of 1.63 g < 1.64 g < 1.65 g< 1.66 g recorded in respective soils of alluvium deposits, coal measures, shale and both coastal plain sands and false-bedded sandstones and were observed to also show no existing variability ($p < 0.05$) among them. GMWD record mean value of 0.16 observed to be the same for all soil groups.

ASC recorded mean value of 8.97 % for soils of shale observed not to be significantly ($p < 0.05$) higher than 8.45 % for soils of false-bedded sandstones, but both were higher ($p < 0.05$) than 7.13 % in coal measure soils, also observed to be higher ($p < 0.05$) than6.35 % recorded in both coastal plain sand and alluvium deposited soils ,implying therefore that soils of shale and false-bedded sandstones were more stable compared to coal measure, coastal plain sand and alluvium deposited soils respectively. DR values of the studied soils, were observed to increase significantly ($p < 0.05$) with trend of alluvium deposited (68.15 %) and coastal plain sands (68.71 %) soils < coal measure soils (70.87%) < false-bedded sandstone soils (75.20 %) <shale soils (76.76 %). Also, mean CDI values showed trend of shale (52.97 %) > false-bedded sandstone (52.86 %) soils> coal measure soils (52.04 %)> coastal plain sands (51.62 %) > alluvium deposited soils (51.33 %), with variability ($p < 0.05$) existing between CDI of alluvium and coal measure soils..Also, CDI of shale and false-bedded sandstone soils varied ($p < 0.05$) with CDI of respective soils of alluvium deposits, coastal plain sands and coal measure soils. CFI was observed to have an inverse relationship with CDI, however the studied soil groups recorded means of alluvium deposited (48.68 %), coastal plain sand (48.39 %) and coal measure (47.97 %) soils observed to be significantly ($p < 0.05$ %) higher compared to means of false-bedded sandstone (47.14 %) and shale (47.04 %) soils. Results observed for DR, CDI and CFI respectively indicates that alluvium deposited, coastal plain sand and coal measure soils have more stable aggregates compared to soils of false-bedded sandstones and shale, therefore contradicting observed results of ASC that shale and false-bedded sandstones were more stable than coal measure, coastal plain sand and alluvium deposited soils respectively. Generally, observed CFI were respectively lower compared to CDI, therefore implying that soils of the existing soils groups of south eastern Nigeria are characterized generally by low stable aggregates, therefore confirming reports of Enyioko *et al.* (2019)that south east soils are prone to degradation especially physical degradation of erosion.

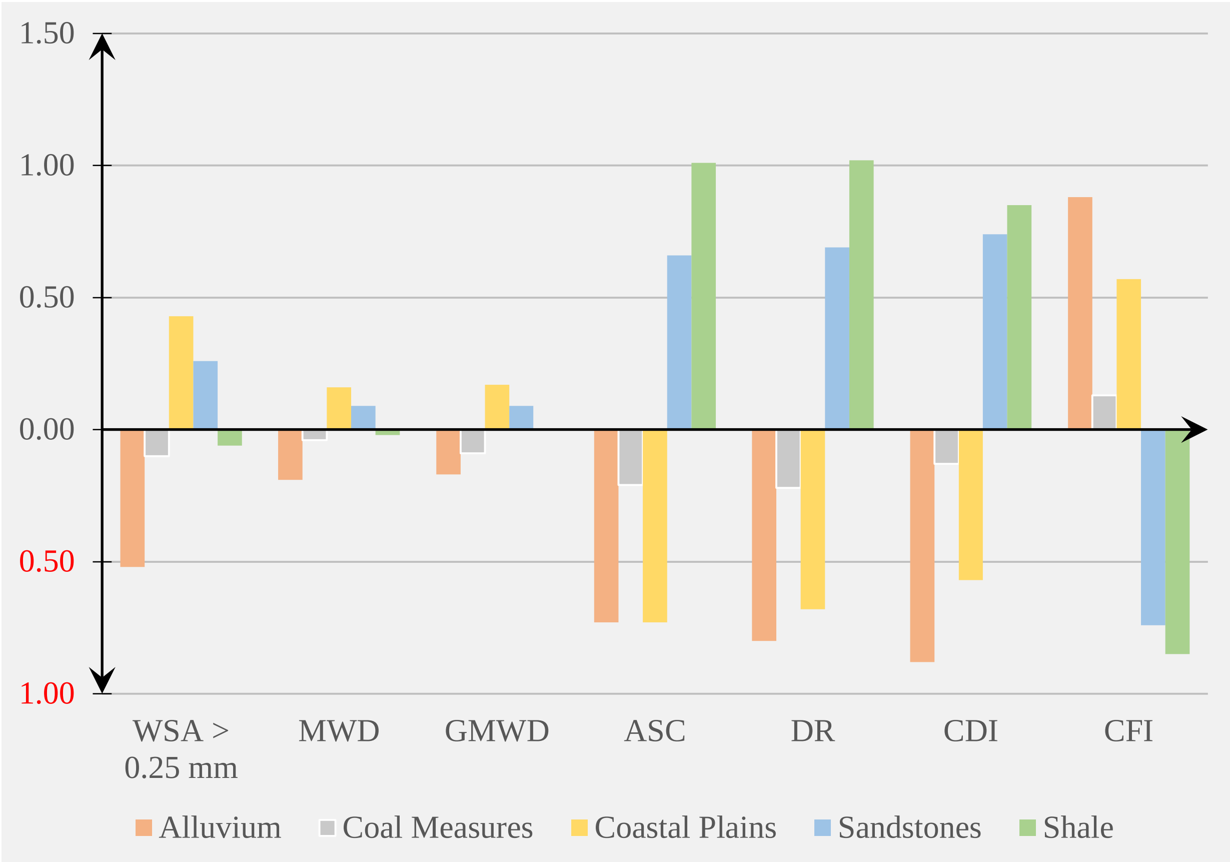

Figure 5: Chart Showing Aggregate Stability Characteristics of the Studied Soils

Table 5: Water Stable Aggregates of different Sieve Mesh diameters of Studied Soils

Location	Water stable aggregate under different (mm) sieve sizes (g)					
	> 2	**1 - 2**	**0.5 - 1**	**0.25 - 0.5**	**WSA < 0.25**	**WSA > 0 25**
	Alluvium/Deltaic Plains					
Akwete	0.14	0.13	0.35	0.83	0.47	1.45
Ikwo	0.17	0.17	0.29	0.74	0.57	1.37
Adani	0.18	0.16	0.25	0.79	0.61	1.28
Umuehi	0.27	0.14	0.20	0.41	0.91	1.02
Mean	**0.19**	**0.15**	**0.27**	**0.69**	**0.64**	**1.28**
	Coal Measures					
Asaga	0.18	0.16	0.30	0.68	1.01	1.32
Afikpo	0.13	0.16	0.34	0.87	1.37	1.50
Nsukka	0.17	0.16	0.25	0.70	0.93	1.28
UmuEzageh	0.25	0.16	0.24	0.60	0.92	1.24
Mean	**0.18**	**0.16**	**0.28**	**0.71**	**1.06**	**1.34**
	Coastal Plain Sands					
Obehie	0.19	0.16	0.30	0.75	1.10	1.40
Owutu Edda	0.20	0.17	0.34	0.77	0.98	1.48
Uzo Uwani	0.20	0.13	0.29	0.73	1.03	1.35
Nekede	0.21	0.17	0.25	0.76	0.76	1.39
Mean	**0.20**	**0.16**	**0.30**	**0.75**	**0.97**	**1.41**
	False-bedded Sandstones					

Isuochi	0.22	0.18	0.25	0.53	0.70	1.18
Igbere	0.09	0.15	0.39	0.99	1.54	1.62
Ngwo	0.16	0.16	0.25	0.71	0.88	1.28
Ihube	0.22	0.17	0.28	0.78	1.26	1.45
Mean	**0.17**	**0.17**	**0.29**	**0.75**	**1.10**	**1.38**
Shale						
Ajata-Ibeku	0.17	0.15	0.32	0.75	1.14	1.39
Amuvi	0.17	0.17	0.32	0.79	1.18	1.45
Agwu	0.18	0.15	0.26	0.71	0.98	1.30
Isu	0.24	0.16	0.23	0.59	0.75	1.22
Mean	**0.19**	**0.16**	**0.28**	**0.71**	**1.01**	**1.34**
Lsd (0.05)	**0.09**	**0.05**	**0.10**	**0.16**	**0.23**	**0.17**

WSA = Water stable aggregates

Table 6: Aggregate Stability Characteristics of the Studied Soils of Studied Soils

Location	MWD	GMWD	ASC	DR	CDI	CFI
	Alluvium/Deltaic Plains					
Akwete	1.65	0.16	6.76	67.50	51.15	48.85
Ikwo	1.71	0.16	6.86	67.87	51.25	48.75
Adani	1.57	0.16	5.79	68.24	51.35	48.65
Umuehi	1.58	0.16	5.98	68.97	51.55	48.45
Mean	**1.63**	**0.16**	**6.35**	**68.15**	**51.33**	**48.68**
Coal Measures						
Asaga	1.62	0.16	6.75	67.43	51.13	48.87
Afikpo	1.69	0.16	8.74	76.28	52.87	47.13
Nsukka	1.51	0.16	6.67	69.36	52.22	47.78
UmuEzageh	1.75	0.17	6.36	70.41	51.92	48.08
Mean	**1.64**	**0.16**	**7.13**	**70.87**	**52.04**	**47.97**
Coastal Plain Sands						
Obehie	1.71	0.16	6.25	69.99	51.81	48.19
Owutu Edda	1.72	0.16	5.79	68.23	51.35	48.65
Uzo Uwani	1.65	0.16	6.67	69.36	52.22	47.78
Nekede	1.57	0.16	6.70	67.24	51.08	48.92
Mean	**1.66**	**0.16**	**6.35**	**68.71**	**51.62**	**48.39**
False-bedded Sandstones						
Isuochi	1.59	0.16	9.46	78.44	53.39	46.61
Igbere	1.67	0.16	7.97	73.83	52.27	47.73
Ngwo	1.45	0.16	9.62	78.92	53.50	46.50
Ihube	1.91	0.17	6.73	69.59	52.28	47.72
Mean	**1.66**	**0.16**	**8.45**	**75.20**	**52.86**	**47.14**
Shale						
Ajata-Ibeku	1.66	0.16	8.04	74.06	52.32	47.68
Amuvi	1.71	0.16	9.37	78.19	53.33	46.67
Agwu	1.58	0.16	11.23	83.40	54.55	45.45
Isu	1.63	0.16	7.24	71.39	51.66	48.34
Mean	**1.65**	**0.16**	**8.97**	**76.76**	**52.97**	**47.04**
Lsd (0.05)	**0.14**	**0.02**	**0.56**	**1.00**	**0.45**	**0.45**

WSA > 0.25 = Water stable aggregates > 0.25 mm; MWD = Mean weight Diameter; GMWD = Geometric Mean weight Diameter; ASC = Aggregated silt and clay; DR = Dispersion ratio; CDI = Clay dispersion index; CFI = Clay flocculation index

Correlation of Structural Properties with Characteristics of Soils of Existing Soil Groups of South East Nigeria

The correlating properties between micro and macro aggregate stability with observed properties of the studied soils are presented in Appendix 1.

The results indicated that ASC, DR and CDI of the studied soils respectively clay ($r = 0.94$; $r = 0.99$; $r = 0.96$, $p < 0.01$), silt ($r = 0.67$; $r = 0.69$; $r = 0.63$, $p < 0.05$), PD($r = 0.92$; $r = 0.97$; $r = 0.95$, $p < 0.01$), %P ($r = 0.91$; $r = 0.96$; $r = 0.95$, $p < 0.01$)and Ksat ($r = 0.96$; $r = 0.99$; $r = 0.96$, $p < 0.01$) as well as EC ($r = 0.64$; $r = 0.66$; $r = 0.65$; $r = 0.59$, $p < 0.05$), SOC and SOM($r = 0.65$; $r = 0.65$; $r = 0.66$; $r = 0.58$, $p < 0.05$)but correlated negatively and significantly with sand content ($r = - 0.94$; $r = - 0.90$; $r = - 0.93$; $r = - 0.89$, $p < 0.01$), BD ($r = - 0.99$; $r = - 0.92$; $r = - 0.97$; $r = - 0.95$, $p < 0.01$) and Av. P ($r = - 0.65$; $r = - 0.65$; $r = - 0.66$; $r = - 0.58$, $p < 0.05$), while CFI correlated positively and significantly with sand ($r = 0.89$, $p < = 0.01$), BD ($r = 0.95$, $p < 0.01$) and Av. P ($r = 0.58$, $p < 0.05$), but correlated negatively and significantly with clay and Ksat ($r = - 0.96$, $p < 0.01$), silt ($r = - 0.63$, $p < 0.05$), PD and %P ($r = 0.95$, $p < 0.01$) as well as SOC and SOM ($r = 0.58$, $p < 0.05$) and EC ($r = 0.59$, $p < 0.05$). This reveals that ASC, DR and CDI of soils of existing soil groups of south east Nigeria increases while CFI decreases with increasing clay and silt contents, particle density, porosity, saturated hydraulic conductivity, electrical conductivity as well as organic carbon and organic matter contents of the soils, with decreasing sand, bulk density and available phosphorus.

Spatial Variability of Measured Soil Properties Contributions to Principal Components

Principal Component Analysis (PCA)was applied respectively for soil mechanical, hydro-physical, chemical reactions, cations and structural characteristics, using principal components with Eigen values ≥ 1, and loading factors ≥ 0.75 to quantify only strongly dependent measured soil properties (Appendix 2a – 2e). Positive loading factors showed increase while negative loading factor decrease.

PCA applied for the mechanical and hydro-physical properties of the soils as well as the soils chemical reactions respectively indicated only the first principal component recorded Eigen value > 1 and accounted for about 90 %, 67 %,and 72 % of the total variation observed in the studied soils. Positive dependence of the studied soils on clay (r^2 = 0.94), silt (r^2= 0.97) and particle density (r^2 = 0.93) as well as porosity and saturated hydraulic conductivity (r^2 = 1.00), electrical conductivity (r^2 = 0.99) and organic carbon/matter (r^2 = 1.00) with negative dependence on sand (r^2 = 0.99), bulk density (r^2 = 0.93), total nitrogen (r^2 = 0.82) and available phosphorus (r^2 = 1.00) were observed.

PCA applied for exchangeable cations and structural stability indices of the soils recorded 2 Eigen values > 1 respectively. The first principal components accounted for 63 % and 58 % variations, and showed positive soil dependence on sodium ion (r^2 = 0.99) and aluminum ion (r^2 = 0.90) contents, aggregated silt and clay (r^2 = 0.94), dispersion ratio (r^2 = 0.95) and clay dispersion ratio (r^2 = 0.92), with negative soil dependence on clay flocculation index (r^2 = 0.92). The second principal components accounted for 20 % and 31 % variations, showing positive necessity on hydrogen ion content (r^2 = 1.00), aggregated silt and clay (r^2 = 0.96), dispersion ratio (r^2 = 0.95) and clay dispersion ratio (r^2 = 0.92) with negative necessity on potassium ion (r^2 = 0.91) and Calcium ion (r^2 = 0.87) contents and clay flocculation index (r^2 = 0.92).

These imply that the spatial variability of soils of different lithology in south east Nigeria is a function of the physical characteristic of particle size distribution (soil texture), bulk and particle density, porosity and saturated hydraulic conductivity, the chemical behaviours of electrical conductivity, organic carbon/matter, nitrogen and phosphorus contents as well as concentrations of sodium, aluminium, hydrogen, potassium and calcium ions and soil micro aggregate stability indices of aggregated silt and clay, dispersion ratio, clay dispersion index and clay flocculation index.

Suitability Evaluation of Studied Soils for Rice Production

The suitability requirements as well as the suitability classes of evaluated properties of the studied soils for rice production are shown in Appendix 3a and 3b respectively.

The evaluation of south east soils suitability to grow indicated that the climatic condition of southeastern Nigeria favors optimal rice production. The evaluated physical conditions of the studied soils revealed that texture of alluvium deposited soils of Akwete (Abia), Ikwo (Ebonyi) and Umuehi (Imo) as well as coastal plain sand soils of Obehie (Abia), Owutu-Edda (Ebonyi) and Nekede (Imo) was not suitable for rice production, but was either moderately or marginally suitable in other studied soils. Generally, soil depth was highly suitable in all alluvium deposited and coastal plain sand soils, while coal measures, sandstones and shale soils indicated moderate to marginal suitability. Also, Shale soil of Agwu was not suitable for rice production in terms of drainage, however, drainage was either highly, moderately or marginally suitable in the studied soils. These showed that the texture of soils of alluvium deposits and coastal plain sands of Abia, Ebonyi and Imo as well as the drainage pattern of soils of shale formation in Enugu did not favour rice production. Also, the evaluated fertility status of the studied soils revealed that suitability of soil pH was moderate in all alluvium, coal measure and shale soils and marginal in coastal plain and sandstone soils for rice production, but organic carbon/matter and cation exchange capacity were unfavorable. Sandstone soils of Igbere show high suitability compared to the generally moderate suitability in terms of base saturation of the studied soils, while phosphorus was observed to generally show moderate suitability in the studied soils but showed marginal suitability in shale soils of Ajata-Ibeku, Amuvi and Agwu. Exchangeable potassium showed high suitability, but marginal suitability was observed for exchangeable calcium and magnesium of the studied soils for rice production. These showed generally that organic carbon/matter content and cation exchangeable capacities of soils did not favour rice production in south east Nigeria. These results therefore indicate generally that while alluvium deposited and coastal plain sand soils of Abia, Ebonyi and Imo as well as shale soils of Enugu are physically not suitable for rice production, in terms of fertility status, soils of south eastern Nigeria are generally not suitable for rice production. This corresponds with Udo *et al.* (2011) and Ovai (2019) that the major suitability limitation of Nigeria soils is soil fertility.

Conclusion

The result of the study generally revealed that the micro aggregate indices of the studied soils interacted with evaluated physical properties as well as electric conductivity, organic carbon/matter contents and available phosphorus, observed to be among indicated properties(sand, silt, clay, bulk density, porosity, Ksat, EC, OC, N, P, K^+, Ca^{2+}, Na^+, Al^{3+} and H^+ as well as ASC, DR, CDI and CFI) with significant influence on the variability of soils of existing soil groups of southeast Nigeria, which were observed to exhibit high susceptibility to physical degradation (CFI < CDI) and low inherent fertility, hence generally not suitable for rice production. Consequently, conservative agricultural practices, especially incorporation of organic residues, mulching and minimum tillage among other practices are recommended to sustain productivity and control degradation of soil resources in the southeast area of Nigeria. Also, further studies on alteration of soils of the existing soil groups of south east Nigeria for optimal rice production as well as other staple food crops is recommended.

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Appendix 1

Correlating Properties between Aggregate Stability Indices and Physiochemical Characteristics of the Studied Soils.

Variables	WSA > 0.25	MWD	GMWD	ASC	DR	CDI	CFI
Sand	0.04	0.15	0.17	0.90**	0.93**	0.89**	0.89**
Clay	0.03	0.19	0.21	0.94**	0.99**	0.96**	0.96**
Silt	0.03	0.07	0.10	0.67*	0.69*	0.63*	0.63*
BD	0.04	0.17	0.19	0.92**	0.97**	0.95**	0.95**
PD	0.06	0.16	0.18	0.92**	0.97**	0.95**	0.95**
%P	0.05	0.16	0.18	0.91**	0.96**	0.95**	0.95**
Ksat	0.02	0.22	0.23	0.96**	0.99**	0.96**	0.96**
MC	0.06	0.03	0.01	0.08	0.06	0.02	0.02
Ec	0.01	0.06	0.06	0.66*	0.65*	0.59*	0.59*
pH	0.29	0.04	0.05	0.06	0.08	0.14	0.14
Oc	0.01	0.07	0.07	0.65*	0.66*	0.58*	0.58*
Om	0.01	0.07	0.07	0.65*	0.66*	0.58*	0.58*
TN	0.06	0.03	0.02	0.09	0.07	0.01	0.01
Av. P	0.01	0.07	0.08	0.65*	0.66*	0.58*	0.58*
K+	0.06	0.40	0.38	0.47	0.45	0.30	0.30
Ca2+	0.09	0.50	0.48	0.42	0.38	0.27	0.27
Mg2+	0.06	0.49	0.47	0.26	0.28	0.22	0.22
Na+	0.11	0.46	0.46	0.26	0.28	0.15	0.15
Al3+	0.01	0.40	0.39	0.05	0.11	0.08	0.08
H+	0.13	0.02	0.02	0.38	0.37	0.35	0.35
ECEC	0.00	0.44	0.42	0.17	0.13	0.02	0.02
%BS	0.14	0.46	0.45	0.42	0.43	0.35	0.35
%Al	0.03	0.44	0.42	0.06	0.11	0.05	0.05

Appendix 2

Principal Components (Loading Factors) with Eigen Values ≥ 1, for:

a) Mechanical Properties of Studied Soils

Variables	Loading factors	
	PC1	PC2
Soil Mechanical Properties		
Sand Contents	0.99	
Clay Contents	0.94	
Silt Contents	0.97	
Bulk Density	0.93	
Particle Density	0.93	
Eigen value > 1	4.51	
%Eigen. Composition	90.20	
Cumulative %Eigen.	90.20	

b) Hydro-physical Properties of Studied Soils

Variables	Loading factors	
	PC1	PC2
Soil Hydro-physical Properties		
Porosity	1.00	
Moisture Contents	0.48	
Hydraulic Conductivity	1.00	
Eigen value > 1	1.99	
%Eigen. Composition	66.56	
Cumulative %Eigen.	66.56	

c) Chemical Reaction Characteristics of Studied Soils

Variables	Loading factors	
	PC1	PC2
Soil Chemical Reactions		
Electrical Conductivity	0.99	
pH	0.19	
Organic Carbon Content	1.00	
Organic Matter Content	1.00	
Total Nitrogen	0.82	
Available Phosphorus	1.00	
Eigen value > 1	4.29	
%Eigen. Composition	71.62	
Cumulative %Eigen.	71.62	

d) Exchangeable Cations of Studied Soils

Variables	Loading factors	
	PC1	PC2
Soil Exchangeable Cations		
Potassium Ion	0.10	**0.91**
Clacium Ion	0.18	**0.87**
Magnesium Ion	0.74	0.39
Sodium Ion	**0.99**	0.36
Aluminium Ion	**0.90**	0.69
Hydrogen Ion	0.42	**1.00**
Eigen value > 1	4.25	1.32
%Eigen. Composition	63.06	19.58
Cumulative %Eigen.	**82.64**	

e) Structural Properties of Studied Soils

Variables	Loading factors	
	PC1	PC2
Soil Structural Properties		
Water Stable Aggregates > 0.25 mm	0.33	0.07
Mean Weight Diameter	0.34	0.07
Geometric Mean Weight Diameter	0.40	0.09
Aggregated Silt and Clay	**0.94**	**0.96**
Dispersion Ratio	**0.95**	**0.95**
Clay Dispersion Index	**0.92**	**0.92**
Clay Flocculation Index	**0.92**	**0.92**
Eigen value > 1	4.04	2.14
%Eigen. Composition	57.80	30.62
Cumulative %Eigen.	**88.42**	

Appendix 2

a) Morphological Properties of studied Soils

Location	Depth (cm)	Texture	Drainage
Akwete	200	Loamy Sand	Well drained
Ikwo	196	Loamy Sand	Well drained
Adani	188	Loamy Sand	Well drained
Umuehi	178	Loamy Sand	Well drained
Asaga	115	Loamy Sand	Well drained
Afikpo	107	Sandy Clay Loam	Poorly drained
Nsukka	146	Sandy Clay Loam	Moderately drained
UmuEzageh	135	Sandy Loam	Well drained
Obehie	155	Sandy Loam	Well drained
Owutu Edda	169	Sandy Loam	Well drained
Uzo Uwani	144	Sandy Clay Loam	Moderately drained
Nekede	200	Loamy Sand	Well drained
Isuochi	96	Sandy Clay	Poorly drained
Igbere	103	Sandy Clay Loam	Moderately drained
Ngwo	85	Sandy Clay	Poorly drained
Ihube	110	Sandy Clay Loam	Moderately drained
Ajata-Ibeku	138	Clay Loam	Poorly drained
Amuvi	79	Sandy Clay	Moderately drained
Agwu	141	Clay	Very poorly drained
Isu	125	Sandy Clay Loam	Moderately drained

b) Rice Production Suitability:

i) Requirements

Variables	S1	S2	S3	N1
Climatic Conditions				
Annual Rainfall	1100 – 1500	900 – 1100	500 – 900	200 – 500
Mean Temperature	> 25	22 – 25	20 – 22	8 – 20
Soil Physical Characteristics				
Texture	Loam	Clay Loam	Clay	Any
Soil Depth	> 150	100 – 150	80 – 100	< 80
Drainage	Well	Moderately	Poorly	Very Poorly
Soil Fertility Status				
pH	6 – 7	5 – 6	< 5	Any
SOC	> 6	4.31 – 6	4.31	Any
CEC	> 25	13 – 25	6 – 12	< 6
%BS	> 75	50 – 75	30 – 50	Any
K^+	> 0.31	0.11 – 0.30	0.11	Any
Ca^{2+}	6 – 12	3 – 6	< 3	Any
Mg^{2+}	6 – 12	3 – 6	< 3	Any

Adopted from FOA, 1976, 1983, Sys, 1985 and Oleye et al, 2002)

S1 = highly suitable; S2 = moderately suitable; S3 = marginally suitable; N1 = not suitable

ii) Classes for Physical Conditions of Studied Soils

Location	Rainfall (mm)	Temperature (^{0}C)	Texture	Depth (cm)	Drainage
Akwete	S1	S1	N1	S1	S1
Ikwo	S1	S1	N1	S1	S1
Adani	S1	S1	S2	S1	S1

Umuehi	S1	S1	N1	S1	S1
Asaga	S1	S1	S3	S2	S1
Afikpo	S1	S1	S2	S2	S3
Nsukka	S1	S1	S3	S2	S2
UmuEzageh	S1	S1	S2	S2	S1
Obehie	S1	S1	N3	S1	S1
Owutu Edda	S1	S1	N3	S1	S1
Uzo Uwani	S1	S1	S2	S1	S2
Nekede	S1	S1	N3	S1	S1
Isuochi	S1	S1	S3	S3	S3
Igbere	S1	S1	S2	S2	S2
Ngwo	S1	S1	S3	S3	S3
Ihube	S1	S1	S2	S2	S2
Ajata-Ibeku	S1	S1	S2	S2	S3
Amuvi	S1	S1	S3	S3	S3
Agwu	S1	S1	S3	S2	N1
Isu	S1	S1	S2	S2	S2

S1 = highly suitable; S2 = moderately suitable; S3 = marginally suitable; N1 = not suitable

iii) Classes for Fertility Status of Studied Soils

Location	**pH**	**SOC**	**ECEC**	**%BS**	**Av. P**	**K^+**	**Ca^{2+}**	**Mg^{2+}**
Akwete	S2	N1	N1	S2	S2	S1	S3	S3
Ikwo	S2	N1	N1	S2	S2	S1	S3	S3
Adani	S2	N1	N1	S2	S2	S1	S3	S3
Umuehi	S2	N1	N1	S2	S2	S1	S3	S3
Asaga	S2	N1	N1	S2	S2	S1	S3	S3
Afikpo	S2	N1	N1	S2	S2	S1	S3	S3
Nsukka	S2	N1	N1	S2	S2	S1	S3	S3
UmuEzageh	S2	N1	N1	S2	S2	S1	S3	S3
Obehie	S3	N1	N1	S2	S2	S1	S3	S3
Owutu Edda	S3	N1	N1	S2	S2	S1	S3	S3
Uzo Uwani	S3	N1	N1	S2	S2	S1	S3	S3
Nekede	S3	N1	N1	S2	S2	S1	S3	S3
Isuochi	S3	N1	N1	S2	S2	S1	S3	S3
Igbere	S3	N1	N1	S1	S2	S1	S3	S3
Ngwo	S3	N1	N1	S2	S2	S1	S3	S3
Ihube	S3	N1	N1	S3	S2	S1	S3	S3
Ajata-Ibeku	S2	N1	N1	S2	S3	S1	S3	S3
Amuvi	S2	N1	N1	S2	S3	S1	S3	S3
Agwu	S2	N1	N1	S2	S3	S1	S3	S3
Isu	S2	N1	N1	S2	S2	S1	S3	S3

S1 = highly suitable; S2 = moderately suitable; S3 = marginally suitable; N1 = not suitable